Study, Analysis and Implementation of Air-Fuel Ratio Control on Perodua Viva for Better Fuel Consumption

by

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CERTIFICATION OF APPROVAL

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Approved by,

____

IR. DR. MASRI BIN BAHAROM

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMAD IKHWAN BIN KORI

ABSTRACT

This project is about the usage of piggyback engine control unit (ECU) to tune the engine in order to obtain the lowest fuel consumption by running in lean combustion. Air-fuel ratio can be defined as the ratio of mass of air to the mass of fuel that is used in combustion process. The air-fuel ratio of a chemically ideal combustion is 14.6:1. The air-fuel ratio setting of vehicle especially that is using electronic fuel injection is controlled by a device called engine control unit (ECU). In order to obtain smaller fuel consumption for Perodua Viva, a leaner air-fuel ratio setting should be used (more than 14.6:1) but the original ECU cannot change the default value set by the manufacturer easily. Therefore, one of the methods to change the air-fuel ratio setting is by using a piggyback ECU. Running the engine in lean combustion can lead to engine damage. Therefore, a range of safe air- fuel ratio need to be found before any tuning can takes place. Engine simulation using GT-Power is performed in order to determine the maximum temperature that can be achieved in different air-fuel ratio settings. Benchmarking test is done to Perodua Viva in order to obtain the initial fuel consumption of the car. The car is then equipped with the piggyback ECU to change the air-fuel ratio parameter of the engine. After the installation, the car is tested again with different air-fuel ratio setting and the fuel consumption of the car for each air-fuel ratio set is tabulated and drawn in appropriate figure. For GT Power simulations, the temperature of the pistons decreases with the increase of air-fuel ratio values. Based on this result, the engine will not be damaged with the increase of air-fuel ratio and can be used for testing later on. The results of the testing showed that the fuel consumption is reduced with the increase of air-fuel ratio.

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CHAPTER 1

INTRODUCTION

Chapter 1 provides the brief introduction about the project, the objectives and the scope of study in order to achieve low fuel consumption by controlling the air-fuel ratio using piggyback devices.

1.1 BACKGROUND OF STUDY

Fuel efficiency and fuel economy of an internal combustion engine are one of the commonly-talked issues nowadays due to the increased price of fuel .This has led the engineers to think about several methods to reduce fuel consumption of a vehicle. Several methods have been introduced which can reduce fuel consumption such as introducing lean combustion to the internal combustion engine.

The main important parameter that can be used to reduce fuel consumption is the air-fuel ratio. Air-fuel ratio is a ratio of mass of air and the mass of fuel used in combustion in an internal combustion engine. The ratio of 14.6:1 (14.6 parts of air to 1 part of fuel) is the ratio for a complete combustion or a stoichiometric combustion can be achieved. This ratio is the most commonly used by the car manufactures to tune their car.

To achieve low fuel consumption for each combustion process that takes place in the engine, less fuel need to be used. In order to achieve that, lean combustion is used.

Lean combustion is a combustion process that used excess air compared to the stoichiometric or theoretical air. Lean combustion can be achieved by adjusting the air-fuel ratio that is used during the combustion process takes place. In order to achieve a more lean combustion process, the ratio should be changed to more than 14.6:1. Lean combustion has the advantages of low fuel consumption, low emission and high efficiency and these advantages have become the factor of why lean combustion is widely used in almost all combustion technology sectors.

Car manufacturers have specified what air-fuel ratio that needs to be used by the engine during the combustion process takes place. Air-fuel ratio of an engine, especially the port injection engine is controlled by a device called engine control unit (ECU). The ECU receives the air-fuel ratio readings of the engine using a sensor called a lambda sensor, which detects the presence of oxygen in the exhaust fumes. The lambda sensor is attached to the exhaust manifold. The air-fuel ratio readings is then compared to the initial value set in the ECU and if the value is not the same, the ECU is then sends the signals to change the air-fuel ratio until the value is the same with the initial value.

It is not easy to change the default air-fuel ratio value inside the ECU since only the car manufacturer’s specified service center can tune the air-fuel ratio. In order to change the value of the air-fuel ratio, two methods can be used, either by using a standalone ECU which replace the original ECU, or only using a piggyback ECU. Compared to standalone ECU, a piggyback ECU is much cheaper and easy to use.

1.2 PROBLEM STATEMENTS

The parameter set by the car manufacturer inside the ECU cannot be changed easily. Only the manufacturer of the car can change all the parameter set inside the ECU. Therefore, in order to change the default air-fuel ratio values, a piggyback device is attached to the original ECU. The piggyback device has its own user interface that makes it easier to tune by other than the car manufacturer itself.

The excessive heat release form lean combustion can cause the fuel mixture to auto-ignite and causes knocking. Excessive heat released also damaging the engine components such as pistons and the catalytic converter (Edgar, 2002). Therefore, suitable air-fuel ratio parameters need to be found in order to reduce the chances of engine damage.

1.3 OBJECTIVES

The main objectives of this project are:

1. To obtain the initial fuel consumption of the Perodua Viva.
2. To analyze the effect of lean air-fuel mixture setting to the fuel usage for Perodua Viva.
3. To obtain a range of air-fuel ratio to be used for testing
4. To use the piggyback ECU to reduce fuel consumption by changing the air-fuel ratio.

1.4 SCOPE OF STUDY

The scope of study for this project is to determine the effect of changing the air-fuel ratio to the fuel consumption of the car. Simulation is being used in order to determine the range of the air-fuel ratio that can be used by the engine so that the engine does not damage due to the lean combustion.

CHAPTER 2

THEORY AND LITERATURE REVIEW

Chapter 2 provides the overview and the information regarding the basics of the combustion process in the internal combustion engine including the air-fuel ratio (air-fuel ratio) and the target air-fuel ratio needed to achieve less fuel consumption. Chapter 2 also provides the information regarding the engine control unit (ECU) which controls the air-fuel ratio during combustion takes place. Due to the disadvantages of the ECU, one device is introduced which is called the piggyback ECU.

2.1 AIR FUEL RATIO AND LEAN COMBUSTION

2.1.1 Air-Fuel Ratio

Air-fuel ratio is a quantity used in the analysis of combustion processes to quantify the amounts of fuel and the air used during combustion (Cengel & Boles, 2007). It is commonly expressed on the mass basis and is defined as the ratio of the mass of air to the mass of the fuel for a combustion process. The air-fuel ratio can be express as:

$$AFR = \frac{m_{air}}{m_{fuel}}$$

The mass m of a substance is related to the number of moles N through the relation,

$$m = NM$$

where *M* is the molar mass. The air-fuel ratio can be expressed on a mole basis as the ratio of the mole numbers of air to the mole numbers of fuel.

The amount of air used in combustion can also be expressed in terms of the equivalence ratio, ϕ and relative air-fuel ratio, λ. Equivalence ratio, ϕ, is the ratio of the actual fuel-air ratio and the stoichiometric fuel-air ratio while relative air-fuel ratio, λ is the ratio of the actual air-fuel ratio and the stoichiometric air-fuel ratio.

The chemically idle air-fuel mixture by weight in which all air and gasoline are consumed occurs with 14.64 parts air and 1 part fuel (14.6:1). Chemist refers to so such a perfect ratio of reactants as stoichiometric. Mixtures with a greater percentage of air are called lean mixtures and occur as a higher number. Richer mixtures, in which there is an excess of fuel are represented with smaller numbers. The rich burn limit for gasoline engine at normal operating temperature is 6.0 the lean burn limit is above 22 (Hartman, 2003).

Table 2.1: Air-fuel mixture and characteristic from Edelbrock (Hartman, 2003)

AFR	Comment
6.0	Rich burn limit (fully warm engine)
9.0	Black smoke/low power
11.5	Approximate rich best torque at wide-open throttle
12.2	Safe best power at wide-open throttle
13.3	Approximate lean best torque
14.6	Stoichiometric air-fuel ratio (chemically ideal)
15.5	Lean cruise
16.5	Usual best economy
18.0	Carbureted lean burn limit
22+	EFI (Electronic Fuel Injection) lean burn limit

`Based on Table 2.2, in order to obtain the least fuel consumption of an internal combustion chamber, the air-fuel ratio setting need be adjusted to be as lean as possible (air-fuel ratio above 14.6). But the effect of leaner setting for conventional engine is the catalytic converter can be easily overheat (Edgar, 2002) and even able to melt the piston. In order to avoid the damages to the engine, the air-fuel ratio need to be adjusted in a safe range.

2.1.4 Lean Combustion

Lean combustion is the combustion which takes place when excess air is provided in the reaction process. Lean combustion occurs when $\phi < 1$ or $\lambda > 1$. The concept is lean combustion refers to condition when the deficient reactant is fuel and the more the fuel lean.(Dunn-Rankin, 2008).

Lean combustion is employed in nearly all combustion technology sectors, including gas turbines, boilers, furnaces and internal combustion engines.

Advantages of Lean Combustion

1. Complete burnout of fuel during hydrocarbon combustion using excess air (Dunn-Rankin, 2008).
2. Minimum fuel consumption occurs in lean combustion where the thermal efficiency is higher (Itow & Durbin, 1979). The relationship between the fuel combustion and the air-fuel ratio can be observed in Figure 1.
3. Maximum power per unit fuel occurs at lean mixture (Itow & Durbin, 1979).
4. Low emissions due to the flames temperature are typically low, reducing nitric oxide formation (Dunn-Rankin, 2008).The relationship between NO_X emission and the air-fuel ratio can be observed in Figure 2.

Disadvantage of Lean Combustion

1. The mixture rate of flame propagation is slower, and the moment of spark must be advance to permit the burn to complete before piston has proceeded too far into the power or expansion stroke (Itow & Durbin, 1979).
2. Low reaction rate, extinction, instabilities, mild heat release and sensitivity to mixing (Dunn-Rankin, 2008).

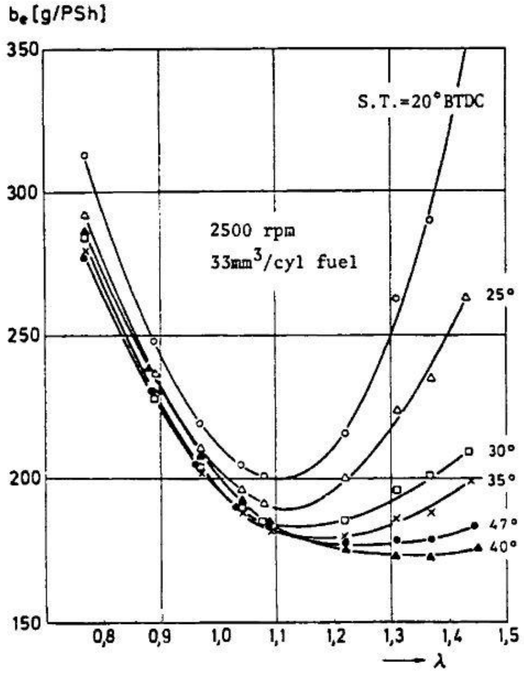


Figure 2.1: Variation of fuel consumption with spark timing and air fuel ratio (Itow & Durbin, 1979)

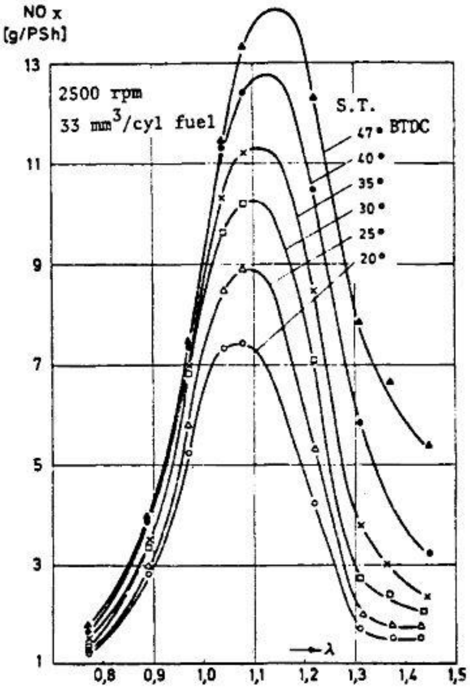


Figure 2.2: Variation of NOX with spark timing and air-fuel ratio (Itow & Durbin, 1979)

Based on Figure 2.1, reducing fuel consumption by using a leaner combustion is possible and could be done.

2.2 ENGINE CONTROL UNIT (ECU)

2.2.1 Introduction

Electronic Fuel Injection (EFI) is commonly used in recent build cars, where the air and fuel are metered separately under computer control, combining only at the last moment in or near the combustion chamber. EFI can define essentially any air-fuel relationship from moment-to-moment, depending on the status of the engine. The relationship between air and fuel in EFI is defined electronically in a computer which is called the engine control unit (ECU).

2.2.2 Working Mechanisms

ECU is used to control several parameters including the air-fuel ratio of an internal combustion engine to keep the engine running. The ECU works in a close-loop system, where the output obtained from the sensor that is allocated at several locations and the output is compared with the preprogrammed parameter from the ECU and readjust the engine based on the parameter provided (Hartman, 2003).

All computer controlled engines is basically function using four step process (Hartman, 2003):

1. Accumulate data in the ECU from engine sensors.
2. Derive engine status from sensors that provide data on engine temperature, speed, loading, intake air temperature and other important factors.
3. Determine and schedule the next event to control spark timing and fuel delivery.
4. Translate computer output signals that directly control actuators.

2.2.4 Original ECU Limitation

The main problem for an original ECU which is installed by the car manufacturer is that the parameter set in the ECU cannot be altered easily. On-site tuning cannot be performed without a secondary device or a new standalone ECU. Therefore, the ECU is attached with a piggyback device which intercept the signals from the sensors and send false signals which is the altered parameter to the original ECU and the ECU will adjust based on the parameter set in the piggyback ECU.

2.2.5 Piggyback ECU

A piggyback ECU is an auxiliary interceptor computer which monitors, extends, truncates, or interrupts signals to and from the original ECU in order to influence or modify injection or spark timing. This type of computer is typically not easy to be programmed and have the potential to initiate a fight with the original ECU by triggering hostile active countermeasure (Hartman, 2003).

The air-fuel ratio parameter of and engine can be adjusted by manipulating the air flow meter in order to reduce the fuel consumption of a vehicle.

CHAPTER 3

METHODOLOGY

The process flow involves for the project is discussed in chapter 3. Several steps in the process flow is discussed especially the details of each part of the project. The project started with benchmarking test, then the engine simulation using GT Power, piggyback ECU installation, car tuning and testing and finally analysis on the result of the testing.

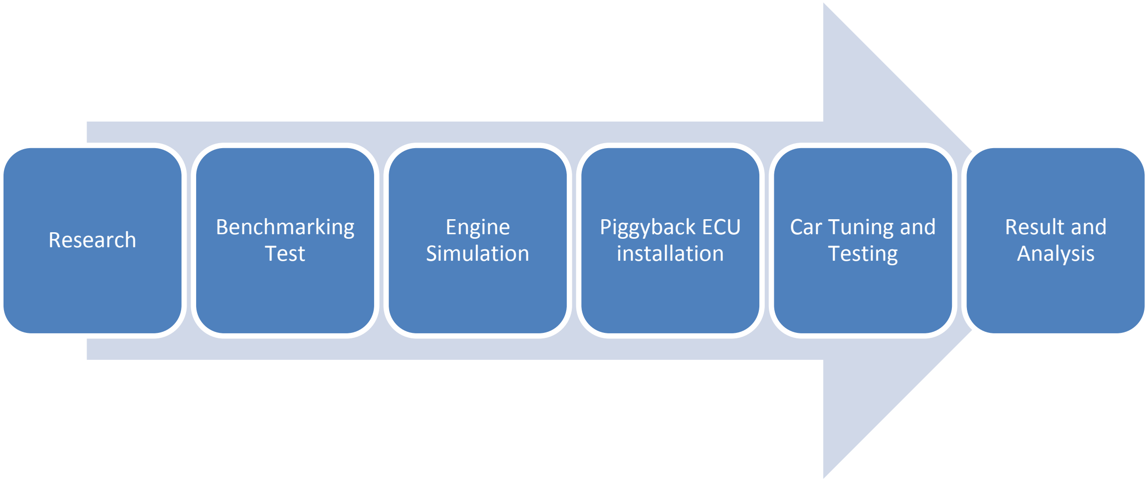


Figure 3.1: Process Flow Diagram

For Final Year Project 2, the project will be started with the engine simulation onwards. The research and benchmarking test had been done during the Final Year Project 1.

3.1 BENCHMARKING TEST

Benchmarking test is performed in order to obtain the initial fuel consumption of the car before any modification to the air-fuel ratio setting is done. There are 2 benchmarking tests done using modified and unmodified car.

3.1.1 Benchmarking Test using Unmodified Car

The car used for this test is Perodua Viva 1.0 L Automatic Transmission with the specification shown in Table 3.1.

Table 3.1: Unmodified car specification

Engine Parameter	Values
Engine Type	EJ-VE
Valve Mechanism	DOHC. 12V (4 valves per cylinder) with DVVT
Total Displacement (cc)	989
Bore x Stroke (mm)	72 x 81
Number of Cylinders	3
Compression Ratio	10
Maximum Output (kW/rpm)	45/6000
Maximum Torque (Nm/rpm)	90/3600
Fuel System	Electronic Fuel Injection (EFI)
Fuel Tank Capacity (Liter)	36.0

The testing parameter used for this benchmarking test is as shown in Table 3.2. Calculations to obtain the average speed and the maximum speed had been made before the testing took place.

Table 3.2: Testing parameter for unmodified car testing

Parameter	Setting Value
Average Speed, V_{avg}	27.43 km/hr
Maximum Speed, V_{max}	54.85 km/hr
Fuel Type	Petronas Primax95
Fuel Amount	1 Liter

In order to determine the initial air-fuel ratio setting, a wideband air-fuel meter which was attached with a lambda sensor is used. The lambda sensor was placed inside the exhaust pipe and the reading was taken.

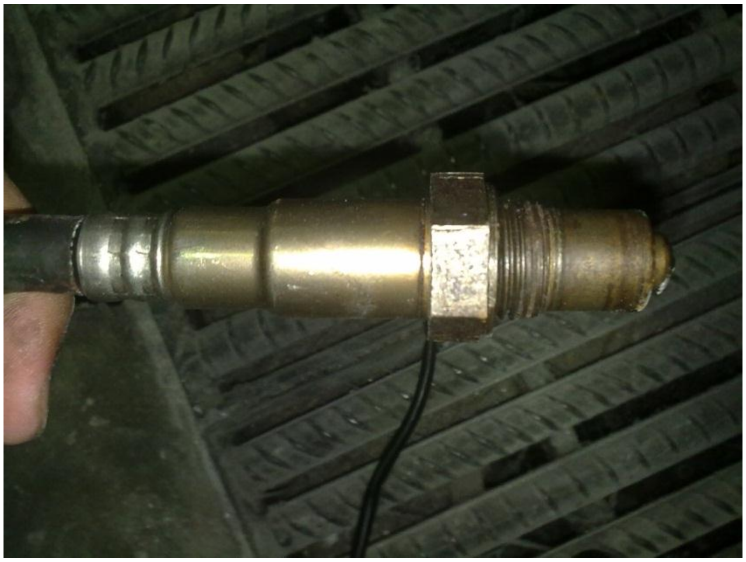


Figure 3.2: Lambda Sensor

Figure 3.3: Wideband Air-Fuel Meter

The distance covered or the test was obtained using a global positioning system (GPS) unit in order to obtain the accurate result of the average speed, the maximum speed and the distance covered.

3.1.2 Benchmarking Test using Modified Car

The Perodua Viva has been modified in order to compete in Perodua Eco-Challenge 2010. The specification of the car is shown in Table 3.3.

Table 3.3: Modified car specification

Engine Parameter	Values
Engine Type	EJ-VE
Valve Mechanism	DOHC. 8V (4 valves per cylinder) with DVVT
Total Displacement (cc)	659
Bore x Stroke (mm)	72 x 81

Number of Cylinders	2
Compression Ratio	10
Fuel System	Electronic Fuel Injection (EFI)
Fuel Tank Capacity (Liter)	1.25
Fuel Pressure	1.5 bar

The parameters used are based on Table 3.4 and the procedure of the testing are based on the previous testing done on the unmodified car.

Table 3.4: Testing parameter for modified car testing

Parameter	Setting Value
Average Speed, V_{avg}	27.43 km/hr
Maximum Speed, V_{max}	54.85 km/hr
Fuel Type	Petronas Primax95
Fuel Amount	250 ml

3.2 ENGINE SIMULATION

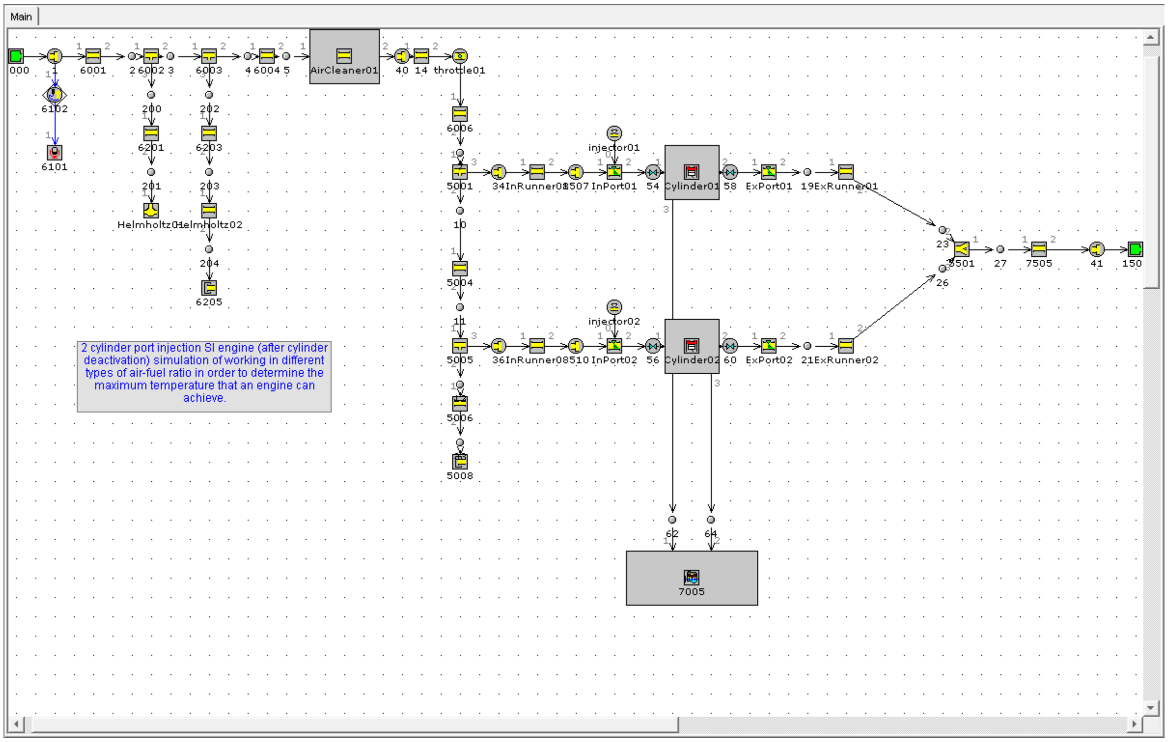
Engine simulation is used to determine the range of air-fuel ratio that can be used before any tuning and testing of different air-fuel ratio settings. The engine simulation is done using software called GT Power. GT Power is used to simulate various types of engine with various types of parameter that can be changed and tested and the result can be easily plotted for analysis. For this project simulation, several air-fuel ratio parameters are tested in order to obtain the maximum temperature of the engine. The temperature of the engine is crucial as very high temperature can lead to engine damage.

3.2.1 Engine Components Material

Before the simulation takes place, the materials used to build the engine components need to be determined to find the temperature before the components fail. The component that is the most commonly damaged due to lean combustion is the piston. The piston commonly is made of aluminum alloy which has the melting temperature of 660°C (933K). The assumption is that the component will fail if the temperature of the component is higher compared to the melting temperature of material used.

3.2.2 Engine Configuration in GT Power

A 2-cylinder, 4-stroke, port-injection gasoline fueled engine was modeled using GT- Power software. The engine configuration used for the simulation is based on the final specification of the engine after the engine is modified. The new modified engine has the specification shown in Table 3.1.



2 cylinder port injection SI engine (after cylinder deactivation) simulation of working in different types of air-fuel ratio in order to determine the maximum temperature that an engine can achieve.

Figure 3.4: Engine Configuration in GT Power

3.2.3 Engine Simulation

The engine will be simulated with air-fuel ratio in the range of 14.6 to 18 at 3500 rpm. The fuel-air ratio is calculated based on the air-fuel ratio values to be used in the simulation.

Table 3.5: Air Fuel Ratio to Fuel Air Ratio Conversion

Air-Fuel Ratio	Fuel-Air Ratio
14.6	0.068
15	0.067
16	0.063
17	0.059
18	0.056

3.3 PIGGYBACK ECU INSTALLATION

The piggyback ECU that is used for the testing is Apexi Super Air Flow Control. This piggyback device only controls the amount of air entered the combustion chamber. The piggyback ECU is attached to the original ECU so that the air-fuel ratio of the car can be controlled by using the user interface provided by the device. The wiring diagram and the wire code can be found in Appendix C and Appendix D.

3.4 CAR TUNING AND TESTING

The testing took place in order to obtain the fuel consumption of the car after tuning takes place. The car is tuned using the piggyback ECU in order to change the air-fuel ratio setting of car. The testing parameter is based on the same parameter used during the benchmarking test and the result of the benchmark test is used to compare the result obtained during the testing using different air-fuel ratio.

The parameter used for the testing can be summarized as follows

Table 3.6: Testing Parameter

Parameter	Setting Value
Average Speed, V_{avg}	27.43 km/hr
Maximum Speed, V_{max}	54.85 km/hr
Fuel Type	Petronas Primax95
Fuel Amount	250 ml

The air-fuel ratio range for the testing is obtained from the GT Power simulation. The range of the air-fuel ratio that is used for the testing is 15 and 15.5. The main reason why the tests were done using the air-fuel ratio setting is due to the knocking which occurs at higher air-fuel ratio. The knocking problem has limit the air-fuel ratio that can be tested. The air-fuel ratio parameter is changed using the piggyback ECU. In order to obtain the desired air-fuel ratio, the piggyback ECU is tuned using trial and error by changing the percentage of air entering the combustion.

3.5 RESULT AND ANALYSIS

The result of the fuel consumption of the car is plotted and compared with the benchmark test result obtained previously to find the least fuel consumption of the car. The results obtained become the proof of the effect of the air-fuel ratio to the fuel consumption of the car.

CHAPTER 4

RESULT AND DISCUSSION

4.1 BENCHMARKING TEST

There are 2 types of benchmarking test that had been conducted during the Final Year Project 1 duration. The first benchmarking test is done on the unmodified car with the same specification from the car manufacturer and the second test is done on the modified car with the modification specified in the last chapter.

4.1.1 Benchmarking Test using Unmodified Car

The initial result of the testing of the unmodified car can be shown in Table 4.1

Air-fuel ratio: 14.6, Fuel Used: 1 liter

Table 4.1: Benchmarking test result for unmodified car

Test	Test 1	Test 2	Test 3
Distance covered, *km*	7.57	11.70	18.90
Average Speed, *km/hr.*	41.0	53.7	34.4
Fuel consumption *(km/liter)*	7.57	11.70	18.90

4.1.2 Benchmarking Test using Modified Car

The initial result of the testing of the modified car can be shown in Table 4.2

Air-fuel ratio: 14.6:1, Average Speed: 50 km/hr, Fuel Used: 0.25 liter

Table 4.2: Benchmarking test result for modified car

Test	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Distance covered, *km*	5.3	5.5	5.6	5.9	5.1	5.7
Fuel consumption *(km/liter)*	21.2	22	22.4	23.6	20.4	22.8

Average Fuel Consumption = 22.07 km/liter

4.2 ENGINE SIMULATION

The result regarding temperature readings of the piston is obtained. The temperature of the piston shows the result of simulation of the running engine at different air-fuel ratio. The Figure 4.1, Figure 4.2 and Figure 4.3 show that the temperature on the surface of the piston is decreasing with the increase of the air-fuel ratio. The fuel-air ratio can be defined as the reciprocal of the air-fuel ratio.

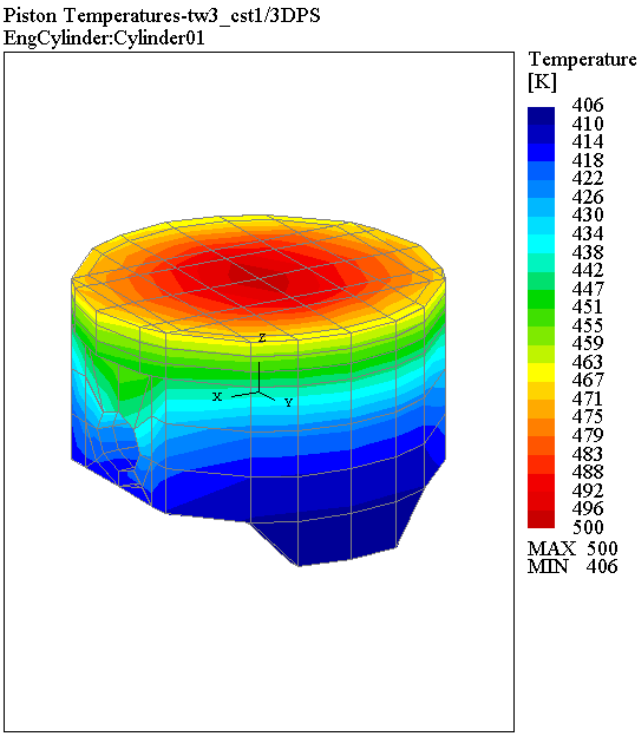


Figure 4.1: Maximum and minimum temperature of the piston at fuel-air ratio of 0.056

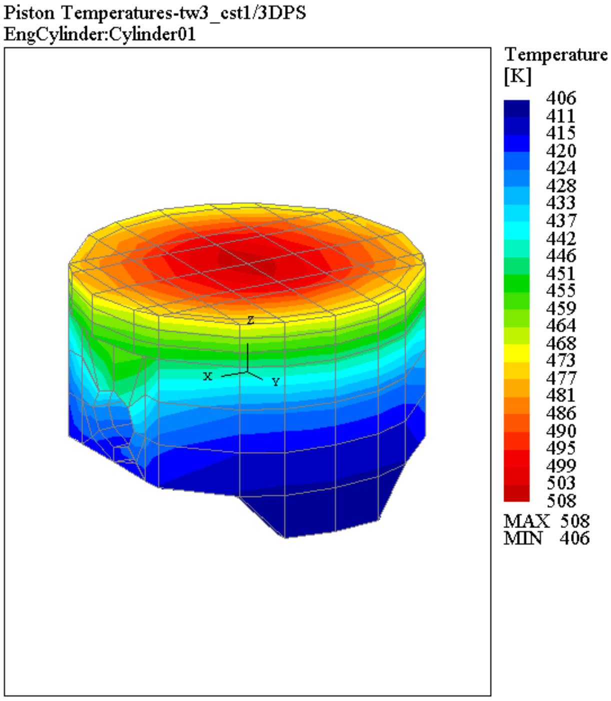


Figure 4.2: Maximum and minimum temperature of the piston at fuel-air ratio of 0.059

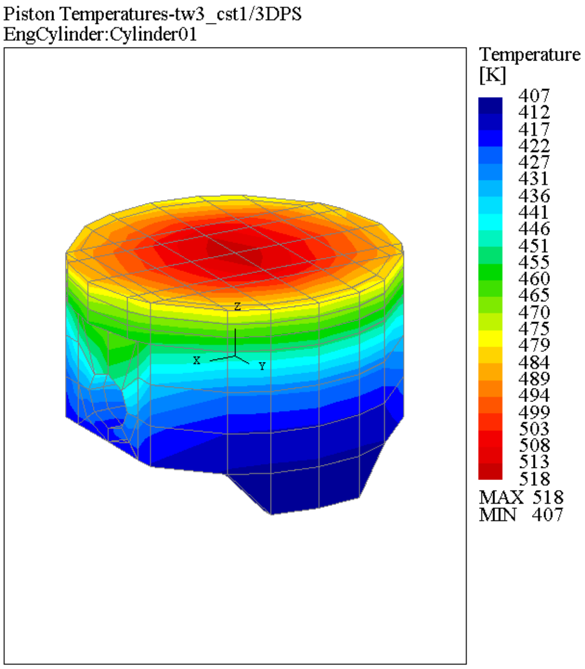


Figure 4.3: Maximum and minimum temperature of the piston at fuel-air ratio of 0.068

The result is then simplified in tabulated form.

Table 4.3: The relationship between the air-fuel ratios to the temperature

Air-Fuel Ratio	Minimum Temperature, K	Maximum Temperature, K
14.6	407	518
17	406	508
18	406	500

4.3 TUNING AND TESTING

The car is tested using different values of air-fuel ratio using the piggyback device. The result of the testing is shown in the Table 4.4 and Table 4.5.

4.3.1 Results

Air-fuel ratio: 15:1, Average Speed: 50 km/hr, Fuel Used: 0.25 liter

Table 4.4: Testing result using air-fuel ratio of 15

Test	1	2	3	4	5
Distance Covered (km)	5.9	5.8	5.5	6.0	5.7
Fuel Consumption (km/liter)	23.6	23.2	22	24	22.8

Average Fuel Consumption = 23.12 km/liter.

Air-Fuel ratio: 15.5, Average Speed: 50 km/hr, Fuel Used: 0.25 liter

Table 4.5: Testing result using air-fuel ratio of 15.5

Test	1	2	3	4	5
Distance Covered (km)	6.2	6.0	6.3	6.1	6.2
Fuel Consumption (km/liter)	24.8	24	25.2	24.4	24.8

Average Fuel Consumption = 24.64 km/liter

4.4 COMPARISON WITH BENCHMARKING TEST RESULT

The result of the benchmarking test and other testing is compared in order to see the improvement of the fuel consumption with different setting of air-fuel ratio. The comparison is done based on the average fuel consumption obtained after all the calculations have been done. The results are compared using graph for easier representation.

Table 4.6: Average Fuel Consumption

Air-Fuel Ratio Used	Average Fuel Consumption (km/liter)
14.6 (Modified)	22.07
15	23.12
15.5	24.64

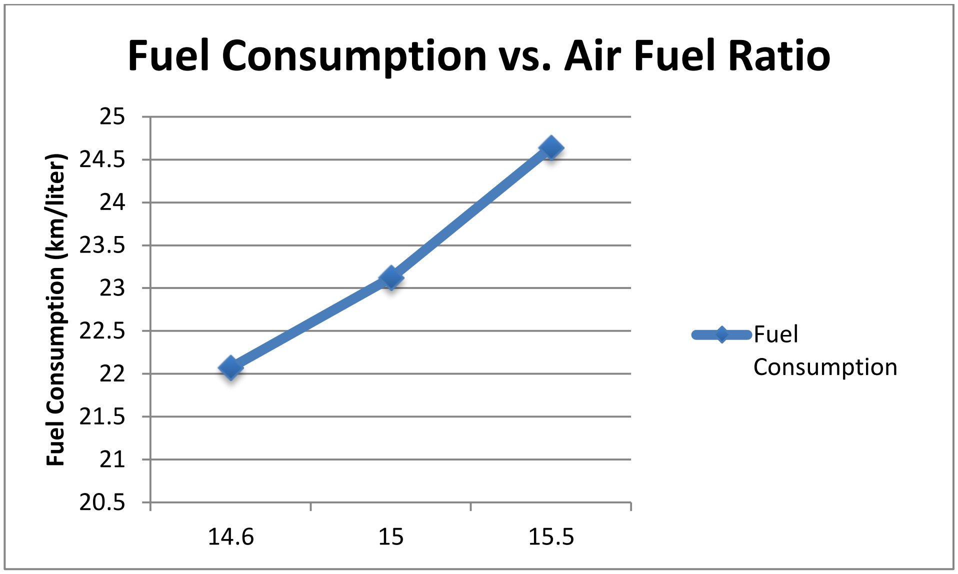


Figure 4.4: Fuel Consumption Comparison

4.5 DISCUSSION

The benchmarking test showed the initial fuel consumption of the car. Two benchmarking tests had been done. The first test show the fuel consumption of the car before the car is modified and the second test showed the result after the modification that did not include the air-fuel ratio modification.

The first test is done during the Final Year Project 1. The result obtained from the first testing cannot be considered as the benchmark fuel consumption of the car since the car is already being modified. The second test results is now taken into as the benchmark fuel consumption since the further testing for air-fuel ratio modifications will be done on the modified car.

The second testing fuel consumption is much lower compared to the first testing because the testing is done on different track. The first testing is done on a wider, less corner track compared to the second testing which have more corners. The corners have caused the driver to brake more and more loses occurs due to tire deformation.

The result from the engine simulation shows that it is possible to run the engine at lean combustion since the final temperature of the piston is lower compared to the stoichiometric mixture. In addition, the combustion is complete of the fuel is more complete and reduces the fuel consumption of the engine. The low temperature during the combustion is caused by the absorption of some heat of combustion by excess air (Itow & Durbin, 1979).

Lean combustion is used during the testing after the benchmarking test took place. The lean combustion uses less fuel per combustion process that takes place. Due to this, the fuel consumption is reduced and more mileage can be obtained. From the comparison done, with the increase of the air-fuel ratio, the fuel consumption is reduced and thus, the mileage increase per liter of fuel.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The research and the benchmarking test are successfully done. Based on the research done, the suitable air-fuel ratio setting that can be used for the car is above 14.7:1. The benchmarking test also includes the initial fuel consumption and should be used for comparison when the next testing takes place with different set of air-fuel ratio parameter that would be used for the car.

The GT-Power simulation shows the relationship between the air-fuel ratios to the temperature inside internal combustion engine with gasoline. The conclusion that can be made based on the simulation results is that the temperature of the piston decreases with the increase of the air-fuel ratio. A reduction of 18 K of the piston temperature can be obtained by increasing the air-fuel ratio up to 18 if there the engine is running smoothly. Therefore, it is safe to run the engine at high air-fuel ratio without damaging the piston, which is made from aluminum alloy.

The tuning and testing was done after both benchmarking test and the simulation took place. From the result obtained, there was reduction of fuel consumption that can be obtained by using lean combustion. The lean combustion has been proved to help reducing fuel consumption and increases the mileage per unit liter of fuel used.

The piggyback ECU is one of the devices that can be used to control air-fuel ratio of an engine. The piggyback ECU intercepts the data from the lambda sensors in and modifies the value of the air-fuel ratio from the lambda sensors and sends the modified value to the ECU.

5.2 Recommendation

For more accurate result, more tested need to be done in order to reduce errors from multiple data obtained during the test. Lean combustion has caused increase of NO_X gases in the exhaust fumes. Therefore, a complex catalytic converter needs to be used in order not to pollute the environment.

The testing for higher air-fuel ratio setting should be done for more results. Before any testing done, further modifications need to be done, especially for engine cooling so that the engine will not be damaged due to high heat release from the engine.

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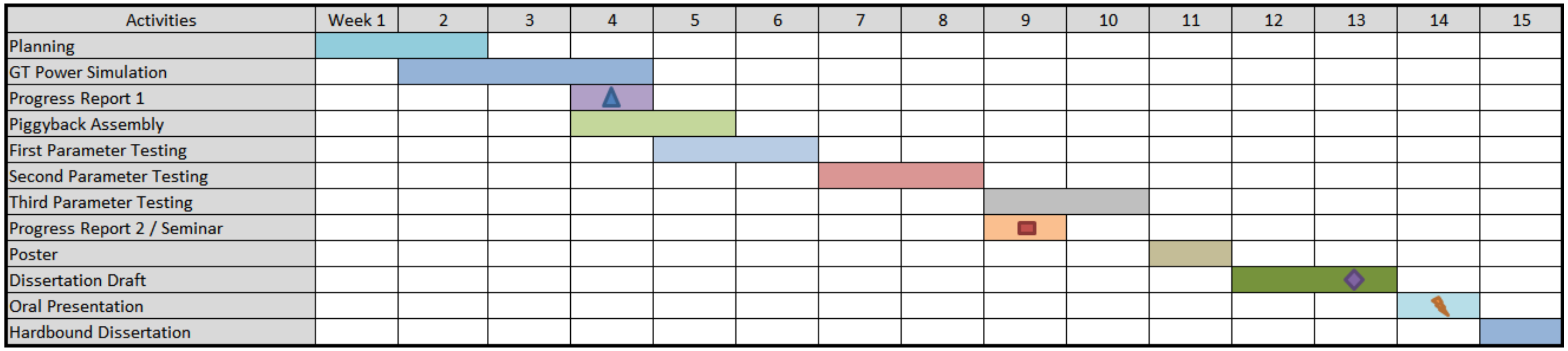
APPENDICES

Appendix A: Gantt Chart for Final Year Project 2

Final Year Project II Gantt Chart



Activities	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Planning	■	■													
GT Power Simulation		■	■	■											
Progress Report 1				▲											
Piggyback Assembly				■	■										
First Parameter Testing					■	■									
Second Parameter Testing							■	■							
Third Parameter Testing									■	■					
Progress Report 2 / Seminar									🟥						
Poster											■				
Dissertation Draft												■	◆		
Oral Presentation														✎	
Hardbound Dissertation															■

Important Dates

▲	20.8.2010
🟥	20.9.2010 - 24.9.2010
◆	1.11.2010
✎	8.11.2010 - 12.11.2010

Appendix B: Testing Parameter Calculations

Before the benchmarking test is taken place, several parameter need to be prepared in order to simulate the real condition during the competition. The rule stated that the car needs to finish a 1.6 km lap in 3 minutes and 30 seconds. Using this, the average speed that need to be accomplished in order to adhere the rule can be calculated as follows:

$$average\ speed, V_{avg} = \frac{total\ distance\ covered, s}{time, t}$$

$$V_{avg} = \frac{1.6\ km}{[(3)(60) + 30]s} \times \frac{3600\ s}{1\ hr} = \boldsymbol{27.43\,\frac{km}{hr}}$$

The maximum speed of the car in order to achieve the average velocity calculated earlier can be calculated considering that the car starts at rest ($V_i = V_{min} = 0$ km/hr.) using the equation:

$$V_{avg} = \frac{maximum\ speed, V_{max} - minimum\ speed, V_{min}}{2}$$

$$V_{max} = [2 \times V_{avg}] - V_{min}$$

$$V_{max} = \left[2 \times 27.43\,\frac{km}{hr}\right] - 0\,\frac{km}{hr} = \boldsymbol{54.85\,\frac{km}{hr}}$$

Appendix C: Wiring Color Code

There are several devices which are connected directly to the ECU of the car that need to be traced to obtain the wire color code for the installation of the piggyback ECU. The table below shows the wire color that attached the sensor to the original ECU. The wire color is obtained by tracing the wires from the sensors to the ECU.

Sensors	Wire Color
Manifold Absolute Pressure Sensor	• Pink-black • Green-black • Yellow • Red
Throttle Position Sensor	• Green • Brown-Yellow • Blue-Pink
Lambda Sensor	• Red • Black-Yellow • Brown-Yellow • Red-White
RPM sensor	• Pink • Blue

Appendix D: Wiring Diagram for Piggyback Installation

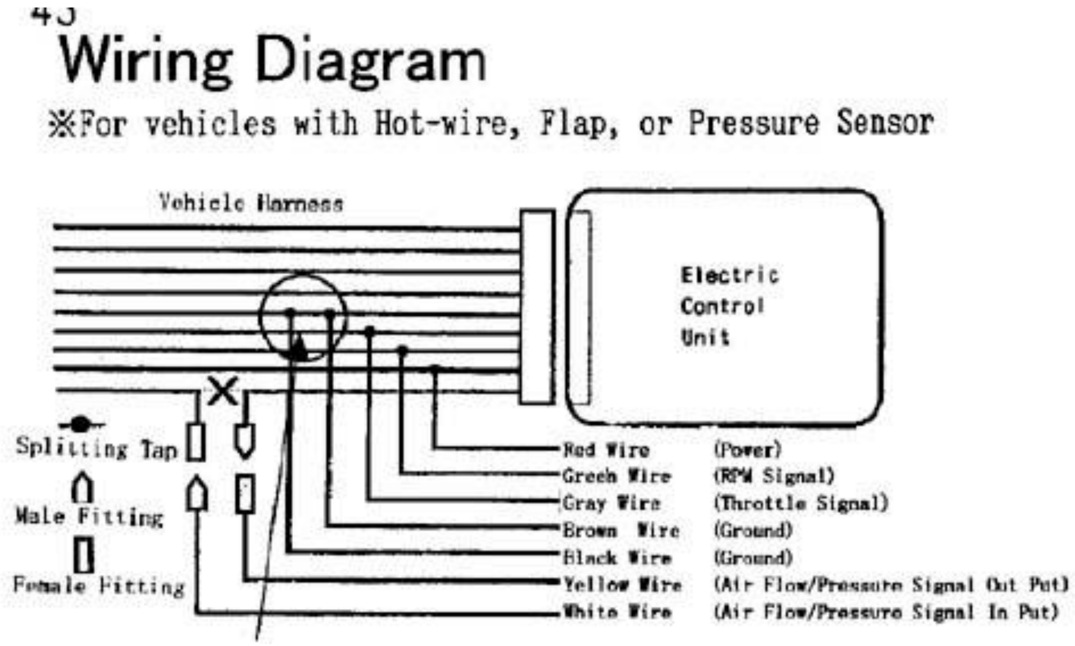


Figure D 1: Wiring Diagram

Source: http://members.cox.net/precisionimage/precisionimage/SAFC.htm

Appendix E: Average Fuel Consumption Calculations

The average fuel consumption calculations were done using the equation:

$$Average\ Fuel\ Consumption\ \left(\frac{km}{liter}\right) = \frac{Total\ Fuel\ Consumption\ for\ all\ tests}{number\ of\ test}$$

<u>For air-fuel ratio of 14.6</u>

$$average\ fuel\ consumption = \frac{21.2 + 22 + 22.4 + 23.6 + 20.4 + 22.8}{6}$$

$$average\ fuel\ consumption = 22.07\ km/liter$$

<u>For air-fuel ratio of 15.0</u>

$$average\ fuel\ consumption = \frac{23.6 + 23.2 + 22 + 24 + 22.8}{5}$$

$$average\ fuel\ consumption = 23.12\ km/liter$$

<u>For air-fuel ratio of 15.5</u>

$$average\ fuel\ consumption = \frac{24.8 + 24 + 25.2 + 24.4 + 24.8}{5}$$

$$average\ fuel\ consumption = 24.64\ km/liter$$